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Thermodynamics and exergoeconomic analysis of geothermal power plants

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ABSTRACT

Fossil fuel reserves (coal, oil, natural gas, etc.) diminish day by day. In addition, rapid advancement of technology causes an increase in the amount of energy needed. This emerging situation resulted in ever increasing importance of renewable energy sources, and various systems are being developed to utilize these renewable energy sources effectively.

In this study, information about Aydın–Salavatli geothermal field's features and working principles of the 2 power plants (DORA 1 and DORA 2) in the region are given. Power plants' energy and exergy efficiencies were calculated with the emphasis on the effects of thermal fluids used in power plants. Also, in this study, some correlations were developed.

Power plants' sections which cause exergy losses were identified. Accordingly, improvement suggestions were presented in this study. Additionally, exergoeconomic analyses were conducted while power plants' investment costs and equipment maintenance costs were taken into consideration.

Contents

Abbreviations: ORC, Organic rankine cycle; SCADA, Supervisory control and data acquisition; OEC, Ormat energy converter; BOP, Balance of plant; NCG, Nitrogen–carbon dioxide gas mixture

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Nomenclature

Cp	specific heat (kJ/kg K)
$\dot{E}$	energy rate (kW)
$\dot{E}x$	exergy rate (kW)
e_x	specific exergy (kJ/kg)
$\dot{I}$	irreversibility (exergy destruction) rate (kW)
f	exergetic factor (%)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (kPa)
s	specific entropy (kJ/kg K)
T	temperature (°C or K)
h	specific enthalpy (kJ/kg)
$\overline{Q}$	heat transfer (termal energy) rate kW
$\dot{W}$	work rate, power (kW)
$\acute{L}_{exergy}$	exergy losses (kW)
$\acute{L}_{energy}$	energy losses (kW)
K	capital cost (TL, USD)
$\dot{F}$	exergy rate of the fuel (KW)
L	thermodynamic loss rate (W, kW)
$\dot{P}$	exergy rate of the product (kW)
R	ration of thermodynamic loss rate to capital cost (W/TL)
R_a	gas constant (kJ/kg K)
$\dot{V}$	Volumetric flow rate (m^3/s)

Subscripts

0	Restricted dead state
1	Dora 1
2	Dora 2
a	NCG mixture output, air
b	Geothermal Steam output
cond	condenser
dest	destruction
en	Energy
ex	Energy
i	=input, successive number1,2,3.
o	out
sys	system
t	turbine
tot	Total
r	reinjection

Greek letters

η	energy or first law efficiency (%)
ε	exergy or second law efficiency (%)
χ	relative irreversibility (%)
δ	fuel depletion rate (%)
ξ	productivity lack (%)

1. Introduction

Geothermal energy production of electrical energy, which is one of the many different plant systems binary conversion plants and installation of the last twenty-five years have increased the well-known. Binary (binary) cycle power plants, geothermal energy to heat the fluid through the heat exchangers, "Rankine" cycle is used together with the transfer of organic liquid [1–3]. Generally, binary (binary) cycle power plants, 150 °C (300 F) temperature near, high amounts of dissolved, non-condensable gas containing corrosive effect on or with the potential of geothermal resources are used efficiently [3]. As in the field of Aydın Salavatli geothermal plants producing wells DORA 1 and DORA 2′s average temperature is 165 °C and 176 °C, respectively, (binary) cycle is used in these power plants.

The aims of the studies dealt with can be listed as below;

- The detection of exergy losses while producing electricity from geothermal energy source which is an alternative energy source,
- The making of energy, exergy and exergoeconomic analysis,
- Presenting recommendations so as to reduce the losses for how to operate the system more efficiently.

In his study Durmus [4] deals with the effects of energy loss and cost the Dora power plant into a plant, a steam line with the lack of analysis of exergy. Ganjehsarabi [5] has dealt with the exergy analysis of DORA 2 power plant operation.

This study differs from [4–38] as follows;

- Dated 14 January 2011 the system performance was analyzed using real field data.
- The exergoeconomic analysis of DORA 1 and DORA 2 plants are made of the work.
- The results of the calculation of the performance of the system to achieve more realistic performance analysis of power plants where the average of the last five years the province of Aydin environmental temperature and pressure cycles are binary values used in the binary-state value is assumed to be dead.
- Exergoeconomic R_{ex} and the R_{en} with the parameters that change depending on outside temperature values were obtained from correlations.
- Similarly, $\dot{E}_x$, $\dot{E}_{en}$ values, exergy and energy efficiencies due to outside temperature changes were examined separately.
- Correlations which show the relationship between R_{ex} and R_{en} values' exergy and energy efficiency were obtained. The correlations between system-specific exergoeconomic parameters and enegy–exergy efficiencies are given.
- The energy and exergy efficiency of DORA 1 and DORA 2 plants are calculated.
- Exergetic factor of the system, relative irreversibility, fuel consumption rate, values of inefficiency are calculated.
- Exergoeconomic and exergetic factor, relative irreversibility, fuel consumption rate, some thermodynamic parameters such as the reference value of inefficiency due to changes in environmental temperature correlations are expressed, and these changes were monitored.

2. Examined areas

In this study, system features of Aydin Geothermal Field in Salavatli DORA 1 and DORA 2 geothermal electricity station power are described.

2.1. Measurements

DORA 1 and DORA 2 plants are kept under control and record with SCADA. Pumps are used in reserve and their works are

controlled by a SCADA system. And future needs of the system according to the signals of the turbine flow rate automatically increases or contribution to reducing the production wells, wells, and production quantities are measured with a flow meter, the fluid produced by the amount of adjusted rates of re-injection-well pumps. Thus, the entire re-injected into the fluid being produced and re-injection wells and production wells work simultaneously. Obtained from the geothermal wells, plants, and to avoid a detrimental effect on the environment re-injected into underground again sent into the atmosphere opening.

2.2. The definition of the system dealt with

Binary plants are accepted as usually above 85 °C and 175 °C at the bottom of the hot dry rock geothermal systems, and are regarded as the most efficient cycles. For this reason, DORA 1 and DORA 2 power plants for electricity generation in geothermal binary cycle is used as a dual-loop system. This dual operating system summary binary cycle, the evaporator geothermal fluid is passed through the evaporator heat transfer through the heat of *n*-pentane, giving that exists, provides the evaporation of *n*-pentane and *n*-pentane evaporating high-pressure turbine shaft passes through and transmits the energy of motion. Kinetic energy is converted to electrical energy with the help of the shaft generator. *N*-pentane, air-cooled condenser through the turbine is completely converted to liquid phase and entering condensed pump pressure is increased. In this way a cycle is obtained.

Both the plant and re-injection wells to production wells in the parts where the current segment decoder, which is far evaporators, Surface Instruments is called Balance of Plant (BOP). Re-injection of geothermal fluid entering the pump evaporators up to entry into Ormat Energy Converter (OEC). There are two *n*-pentane convertor in O.E.C system closed-loop system, which has two cycles of *n*-pentane. The evaporator 1, Pre-heater 1, the Turbine 1 and the air-cooled condenser where the segment decoder 1, id called Chapter 1, Evaporator 2, Pre-heater 2, the Turbine 2 and 2 to the air-cooled condenser where the segment decoder is called the Section 2.

2.2.1. DORA 1 features

Dora 1 area is located in a distance 22 km from Aydın, between the towns of the province of Aydın Sultanhisar, and Köşk. Geographic coordinates latitude (Φ): 37,054′ North, Longitude (λ): 28,009′ East, and Altitude (h):70 m. The region is located in the southern part of the Buyuk Menderes Graben. The slope of the land is almost negligible. The average slope is approximately between 0.2 and about 5%. There are no settlements in the area. According to the detailed geological and geophysical researches done between 1980 and 1984 the result of the width of the geothermal field is estimated to be 16 km^2 [6]. The gross amount of power (full power) is 7.3 MW and its' explicit power is 6.5 MW. Dora 1′s annual production capacity of electricity is 55,000,000 kW h. In Fig. 1, the central image of DORA 1 is shown.

There are two production wells and re-injection wells in this station. The names of production wells are respectively, AS-1 and ASR-2 and the name of re-injection well is AS-2. The distance between production well AS-1 and the OEC production well with the electricity production is 850 m, and the difference in their height (elevation) is +8.7 m. ASR-2 production well is on-the field of electricity production and it is 75 m away and there is difference in height. The distance from Reinjection wells AS-2, to the OEC is 1250 m and height difference is −6.2 m [4]. Production datum of DORA 1 wells are given as detailed in Table 1.

An equipment exchange, each numbered entry and exit of equipment, energy and exergy analysis was calculated. Fig. 2 shows the DORA 1 central scheme.

AS-1 production wells 1170 kPa, 165 °C, and 75.6 kg/s enters with a control valve of the geothermal well head. In the output of the parser as a two-phase vapor and liquid extracted from the liquid phase of the geothermal fluid in the collector than 1 results are shown in vapor phase, the other wells at the beginning of the ASR-2 Parser 2′ combines with steam output of the OEC system enters Evaporator 2.

Geothermal production wells ASR-2 164 °C, 692.6 kPa, 72.9 kg/s. go, well head enters a control valve. Parser 2 to 72.42 kg/s, 670 kPa, 158.5 °C geothermal fluid from the fluid phase of the collector to 2 falls. One of the main exits of the Collector 2 is a spare one of the two hot water pump power of 30 kW geothermal fluid pressure of 817 kPa with upgraded, 158.56 °C, 69.72 kg/s and tanks is pumped to the heat exchanger.

The central hot water pumps which are in the output of Collector 1 and 2 come together at the exit of the collector field land in discharge lines at some point after the OEC geothermal fluid state system as 158.55 °C, 700 kPa, 142.14 kg/s evaporation falls to 1. Parser 1 and 2 vapor phase geothermal fluid from the two lines come together at some point after the OEC in the central lands belong to the system as steam from there 163 °C, 605 kPa, 6.36 kg/s flow rate entering Evaporator 2 equipment.

Geothermal fluid entering the Evaporator from 1 to 2 Evaporator 113.9 °C, 600 kPa Evaporator than 2 out of 2 in the form

Fig. 1. DORA 1 power plant image.

Table 1
Properties of wells and the values of production in the DORA 1. (14.01.2011 plant data).

Types of wells	Names of wells	The wells depths (Meters)	Temperature (°C)	Pressure (kPa)	The fluid flow rate (kg/s)
Production well	AS-1	1517	165	1170	75.6
Production well	ASR-2	1300	165	692.6	72.9
Reinjection well	AS-2	950	81,7	1709	146

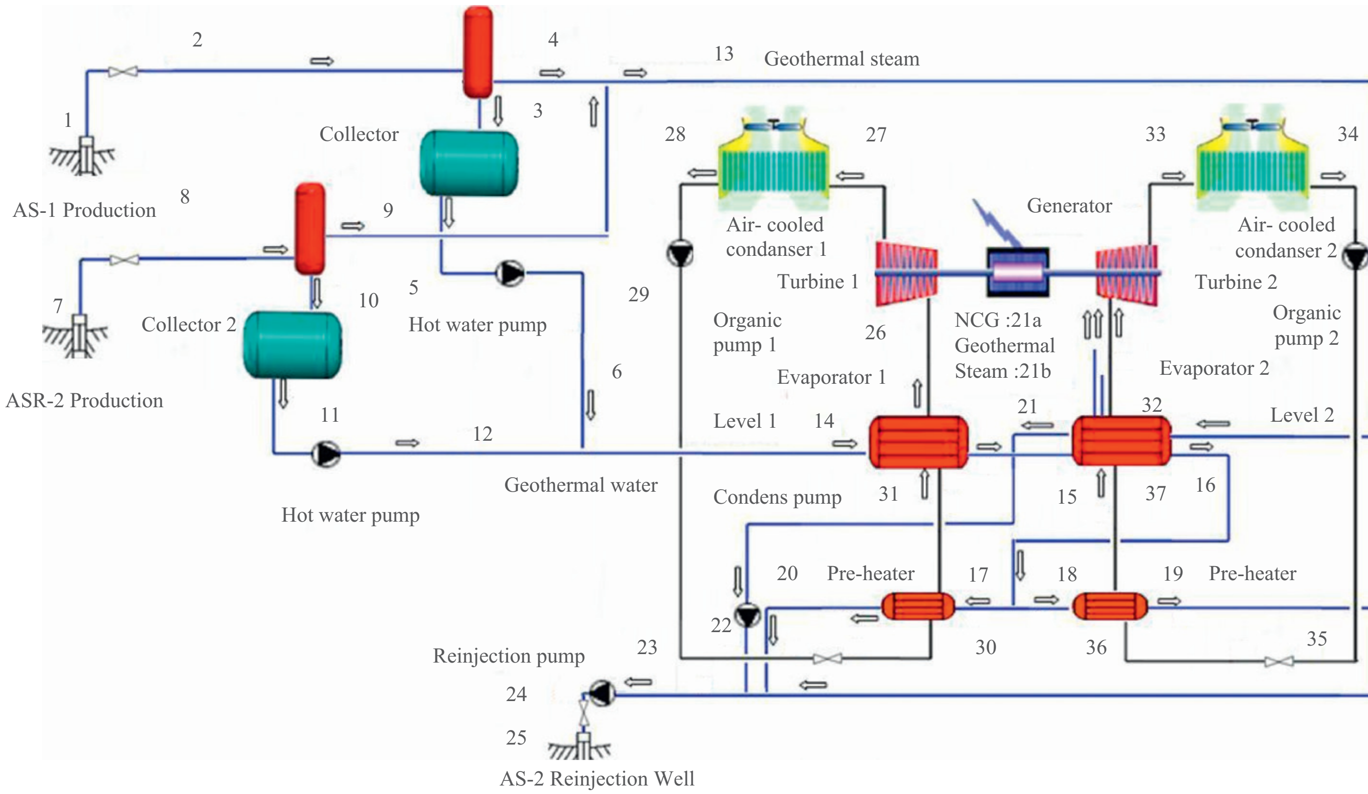

Fig. 2. DORA 1 power plant diagram.

of pre-heater 1 and the pre-heater is divided into two parts. Pre-heater 1 input is 113.9 °C, 600 kPa, 71.07 kg/s and Pre-heater 2 input is 113.9 °C, 600 kPa, 71.07 kg/sec. Pre-heater 1 to 73 °C, 600 kPa, 71.07 kg/s ta from the geothermal fluid and the pre-heater 2 to 76.4 °C, 550 kPa, 71.07 kg/s of geothermal fluid from the pump through condensed is sent Drainage pumps. Evaporator 2 to 112.9 °C, 505 kPa, 2.03 kg/s NCG and 0.48 kg/s steam is liquidated. NCG is a density of CO2 gas in the gas purification for use in the production of coke is sent to a different company. Reinjection wells AS-2 input is 81.7 °C, 1709 kPa, 146 kg/sec.

N-pentane, closed Rankine cycle for Section 1; Evaporator 137.6 °C from 1 to 1200 kPa, 54.55 kg/s to 1 enters the turbine of the *n*-pentane. Turbine 1′ from the 75.4 °C, 80 kPa, air-cooled condenser to 1, enter. 30.2 °C air-cooled condenser, enters with the Organic Pump 1. DORA 1, part 1 and part 2 in the Organic Pump 1 and Pump 2 are used, respectively, the amounts consumed power: 175 kW and 150 kW truck. *N*-pentane, closed Rankine cycle for part 2; Evaporator 2 to 111.4 °C, 750 kPa, 63.96 kg/s of the *n*-pentane in the Turbine 2′ enters. Tubin 2 to the *n*-pentane, 68 °C, 110 kPa, air-cooled condenser to 2 enters. 34.9 °C with air-cooled condenser organic Pump 2′ to enter. Organic Pump 2 output 35.70 °C, 750 kPa with 2 enters the preheater.

System status, or when any failure condition occurs, the test for the system to temporarily stop production from wells in the geothermal fluid entering the central reinjection wells should be sent. For this purpose, in some parts of the system the drain pools of water and steam silencers are used.

2.2.2. DORA 2 features

DORA 2 area is located 20 km east of Aydin. The wells built between 1987 and 1988 and called AS-1 and AS-2 and 1510 m, and 962 m depths, respectively The highest temperature obtained

Fig. 3. DORA 2 power plant image.

Table 2
Properties of wells and the values of production in the DORA 2. (January 14, 2011 plant data).

Types of wells	Names of wells	The wells depths (Meters)	Temperature (°C)	Pressure (kPa)	The fluid flow rate (kg/s)
Production well	AS-3	1419	176	1591	117.96
Production well	AS-4	1350	174	1618	112.54
Reinjection well	ASR-4	1900	69.1	1300	113.85
Reinjection well	ASR-5	1300	68.2	1319	113.85

from the wells 171 °C. A private company Aegean Energy in order to build power plants with a capacity of 8 MW_e obtained a license from Energy Regulatory Board [7]. Opened in 3 May 2009, DORA 2 plant capacity is 9.5 MW of 3 Ap, the annual electricity production is 70,000 MW h. The field is 26 km away from the province of Aydin and it is within Sultanhisar and Pavilion boundaries. DORA 2, the same field in, is the second geothermal energy power performed by the Menderes Geothermal Power Generation Inc. DORA 1 is 4 km away this power and has the same technical characteristics with the DORA 2 plants. Fig. 3 shows the image of DORA 2 power plant.

DORA 2′s gross power plant (installed capacity) is 11.2 MW and its absolute power plant is 9.8 MW. Annual production capacity of electricity is 85,000,000 kWh. There are three production wells one of which is spare and two re-injection wells. The names of production wells are respectively, AS-3, AS-4 and ASR-1 is the replacement production well, and the names of the Reinjection wells are ASR-4 and ASR-5.

The production wells of DORA 2 are AS-4 and AS-3. The height of AS-4 from sea level is 88.4 m and AS-3′s is 78.9 m. ASR-1 (spare) production wells are not used; the sea level is 68 m height. The wells of DORA Reinjection of 2 are ASR-4 and ASR-5. ASR-4′s height from the sea level is 56 m and ASR-5′s height from the sea level is 53 m. DORA 2′s well production datum are given in detailed in Table 2.

An equipment exchange, each numbered entry and exit of equipment, energy and exergy analysis was calculated. In Fig. 4, central scheme of DORA 2 is shown.

AS-4 production wells 1591 kPa, 176 °C, and 112.54 kg/s with the control valves of the geothermal fluid enters the well head. In the output of the parser as a two-phase vapor and liquid extracted from the liquid phase of the geothermal fluid in the collector than results are shown in vapor phase, 2 steam output of the parser enters the system, combined with OEC. Parser 1 from 109.94 kg/s, 1,259 kPa, 176 °C the liquid phase geothermal fluid enters into Collector 1. The parser 1 than 913 kPa, 176 °C and 2,60 kg/s in the vapor phase of geothermal interest. The two fluid phases 1 and 2 fluid Parser OEC combined in a single pipe steam system is entering the Evaporator 2 equipment falls from there. Evaporator 2 input at 170 °C, 792 kPa, 5.05 kg/s. Collector 1 and Collector 2 at the exit of the hot water pumps and AS-3 wells within the area of discharge lines come together at some point after the thermal water system, as OEC 169 °C, 1180 kPa, 225.45 kg/s falls to Evaporator 1.

The geothermal fluid in the vapor and liquid phase separator 2 AS-3 geothermal production wells 1618 kPa, 174 °C, 117.96 kg/s of is also divided into two. The liquid phase geothermal fluid 115.51 kg/s and 1254 kPa, 174 °C enters from Parser 2 into Collector 2. Parser 2 to 871 kPa, 174 °C and 2.45 kg/s'-phase geothermal fluid is steam. As ASR-1 is spare production wells it has no features. The evaporator system in OEC 1 outlet is 124.4 °C, 1,180 kPa, 225.45 kg/s. From 1 to 2 out of the evaporator entering the geothermal fluid at 100 °C, 1130 kPa Evaporator 2 than out of in the form of pre-heater 1 and the pre-heater 2 is divided into two parts. Evaporator 2 to 91.2 °C, 940 kPa, 2.69 kg/s in the NCG, and 91.2 °C, 940 kPa, 0.097 kg/s steam is liquidated. In to *t* the evaporator 2 and condensed pump 96.9 °C, 1,140 kPa, 2.25 kg/s of geothermal fluid, the other pre-heater 1 and pre-heater 2 combined with the output of the geothermal fluids are sent to re-injection pump inlet. Re-injection wells ASR-4 entry 68.20 °C, 1319 kPa, 113.85 kg/s. ASR-5 Re-injection wells input 69.10 °C, 1,300 kPa, 113.85 kg/s.

N-pentane, closed Rankine cycle for Section 1; evaporation from 1 to 136 °C, 1149 kPa, 116.61 kg/s enters turbine of the *n*-pentane Turbine 1. Turbine 1 from the 81.3 °C, 177 kPa, enters air-cooled condenser. Air-cooled condenser to 40.4 °C and enters the Organic Pump 1. Organic Pump 1 output 41.5 °C, 1070 kPa with a Pre-heater 1 enters. Pre-heating from 1 to 89.2 °C, and Evaporator 1 to, enters. Section 2 for the *N*-pentane, closed Rankine cycle; Evaporator 2 to 95.3 °C, 440 kPa, 92.24 kg/s of

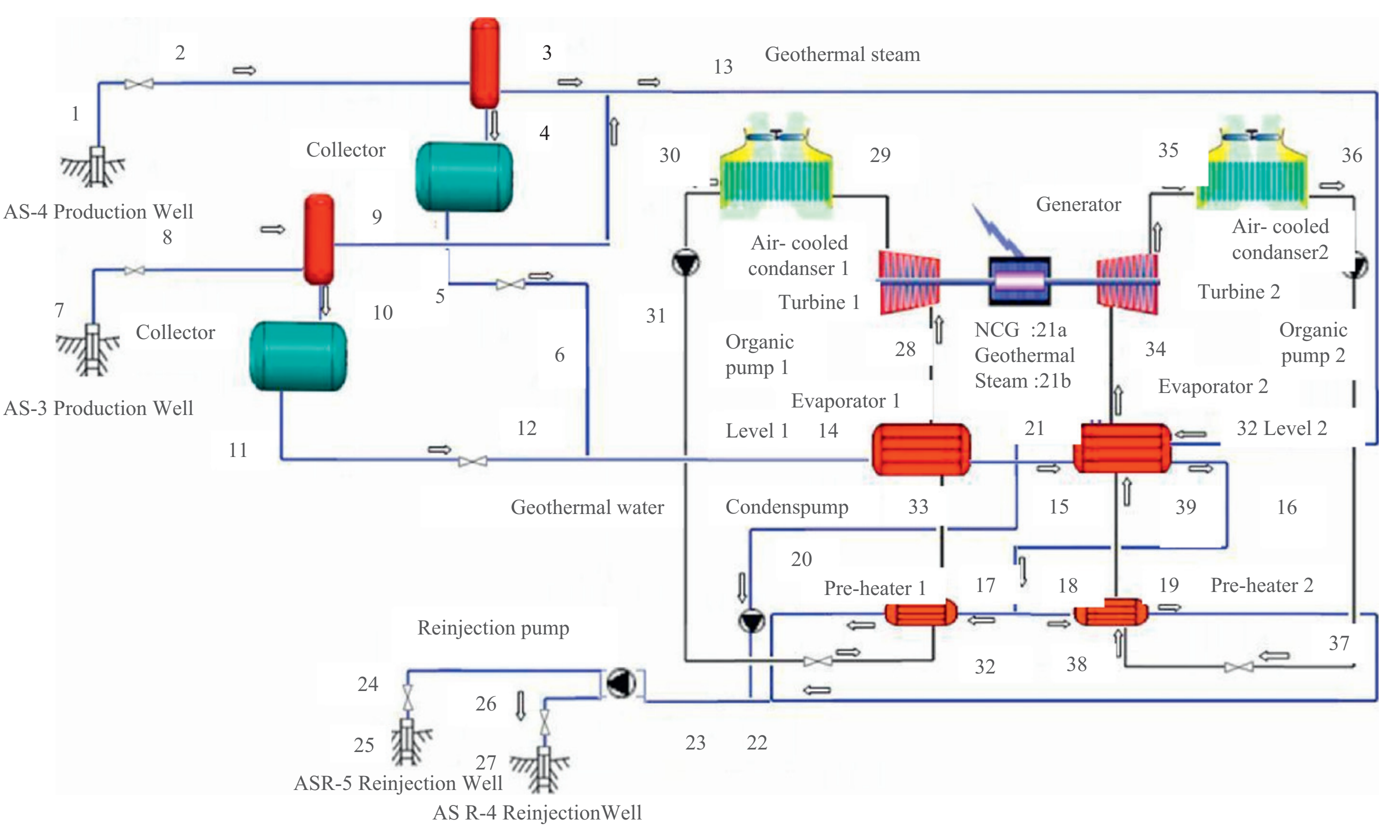

Fig. 4. DORA 2 Power plant diagram.

the *n*-pentane in the Turbine 2 to enters. Turbine 2 to the 67.7 °C, 125 kPa enters the air-cooled condenser 2. Air-cooled condenser 38.8 °C, 125 kPa, with the Organic Pump 2 to enter. Organic Pump 2 out 39.50 °C, 440 kPa, with the Pre-heater 2′ comes up. Pre-heater 2 to 92.3 °C, 440 kPa, enters Evaporator 2.

3. Uncertainty analysis

Measure deviations have been observed because of friction in measuring devices and electronic oscillations. As his situation is higher than normal, it does not only cause an error in measured data but also it makes the thermodynamic values of the entire system faulty and causes the system to operate efficiently incorrectly. These errors are called "uncertainty". In order to minimize the uncertainties in the systems, the measuring instrument uncertainty analysis should be done before it is provided and if possible, lower rather than higher value in the event of uncertainty should be taken with a measuring device.

In this study, the uncertainty analysis of geothermal power plant measuring devices used in power plants DORA 1 and DORA 2 is done and results are shown in Table 3. Tables of the uncertainty taken from property values is ± 0.20,

4. Analysis

In this study energy, exergy and exergoeconomic analysis was conducted. Exergy analysis is a combination the first and second laws of thermodynamics, and the environmental conditions are taken into account. There was a steady development in exergy analysis for many decades. This situation has become the most appropriate tool for the thermodynamic analysis and process optimization. Exergy is defined as the maximum work bringing a system into equilibrium with its surroundings [8]. Exergonomic analysis is important for designer as the cost to operators is an important factor in the therefore quite useful. Exergoeconomic analysis can be done basing on the initial investment cost of the business [e.g., [9–28]].

Here are some of the assumptions anticipated in the analysis

1. The system operates under steady-state conditions.
2. Potential and kinetic energy and exergy exchange have been neglected.
3. Ambient temperature and atmospheric pressure are taken real environmental conditions (the restricted dead state).
4. The last five-year average of the province of Aydin environmental pressure and temperature values (the restricted dead state) is accepted as P_0=100.71 kPa and T_0=18.28 °C.
5. Kinetic exergy, potential exergy and chemical exergy have been neglected.
6. Friction losses are ignored.
7. 14.01.2011 plant data are used.
8. Thermal water physical properties are taken as the same with water's. This state of non-condensable gases and thermal water, of the other chemical properties has been neglected.
9. Air is considered an ideal gas.
10. Mechanical efficiency of fan used air-cooled condenser is accepted as 0.85.

4.1. Mass, Energy and exergy balance equations.

Mass balance equation is as follows.

$$\Sigma \dot{m}_i = \Sigma \dot{m}_o \tag{1}$$

In Eq. (1), $\dot{m}$ is mass flow rate (kg/s), with its sub-indices "*i*" shows input, and "*o*" shows output. The mass balance equations of DORA 1 and DORA 2 power plants;

$$\Sigma \dot{m}_i - (\Sigma \dot{m}_a + \Sigma \dot{m}_b) - \dot{m}_r = 0 \tag{2}$$

Energy balance equation is as follows:

$$\Sigma \dot{E}_i = \Sigma \dot{E}_o \tag{3}$$

In this equation, If it is thought that kinetic energy and potential energy is neglected and is edited for open systems;

$$\overline{Q} + \sum \dot{m}_i . h_i = \dot{W} + \sum \dot{m}_i . h_o \tag{4}$$

In the equation above $\overline{Q} = \overline{Q}i + \overline{Q}o$ shows the net amount of heat transfer, $\dot{W} = \dot{W}i + \dot{W}o$ shows net amount of work and h shows the enthalpy of unit mass. The amount of net work for the system discussed;

$$\dot{W}_{net} = \dot{W}_t - \sum \dot{W}_{\text{the power of consumed}} = \dot{W}_t - \sum \left(\dot{W}_{pumps} + \dot{W}_{fans} + \cdots \right) \tag{5}$$

Eq. (5) is obtained.

Energy efficiency the of thermal systems;

$$\eta = \frac{\sum \dot{E}_o}{\sum \dot{E}_i} = \frac{\dot{W}_{net}}{\sum \dot{E}_i} \tag{6}$$

is expressed with Eq. (6).

There is fan work due to the use of air-cooled condenser in this system. For this reason fan account is needed. Fan power;

$$\dot{W}_{fan} = \frac{\dot{m}_{air} (h_{air,i} - h_{air,o})}{\eta_{mechanic}} \tag{7a}$$

Or;

$$\dot{W}_{fan} = \frac{\Delta P \dot{V}}{\eta_{mechanic}} \tag{7b}$$

Equations can be calculated. Here ΔP refers to the differential pressure in kPa fan input and outputs of. $\dot{V}$ is volumetric flow rate (m^3/s).

The specific physical exergy can be calculated from (8a),

$$e_x = h - h_0 - T_0 (s - s_0) \tag{8a}$$

Eq. (8b) can be used in gas the air specific dealt with the system air-cooled condenser (condenser), due to the use of air in case of acceptance of the ideal exergy [15], the calculation:

$$e_{xair} = C_{p,air} (T - T_0 - T_0 \ln(T/T_0)) + R_{air} T_0 \ln(P/P_0) \tag{8b}$$

$$\dot{E}_x = \dot{m} . e_x \tag{9}$$

here T_o is the restricted dead state (reference state) temperature, h and s geothermal fluid for the enthalpy and entropy of any state, with the restricted dead state. Mass flow rate corresponding to h_0 and s_0 be any product of the corresponding exergy gives a ratio of exergy.

Equations of exergy efficiency and exergy loss of the equipment;

Exergy efficiency of the turbine;

$$\varepsilon_t = \frac{\dot{W}_t}{\dot{E}_{xi} - \dot{E}_{xo}} \tag{10}$$

Exergy loss of the turbine;

$$\dot{I}_t = (\dot{E}_{xi} - \dot{E}_{xo}) - \dot{W}_t \tag{11}$$

Exergy efficiency used as a heat exchanger and for preheater Evaporator;

$$\varepsilon_{heat\ ex} = \frac{\dot{E}_{xn-pentan,o} - \dot{E}_{xn-pentan,i}}{\dot{E}_{xthermal\ water,i} - \dot{E}_{xthermal\ water,o}} \tag{12}$$

Exergy loss used as a heat exchanger and for preheater Evaporator;

$$\dot{I}_{heatex} = (\dot{E}_{xthermalwater,i} - \dot{E}_{xthermalwater,o}) - (\dot{E}_{xn-pentan,o} - \dot{E}_{xn-pentan,i}) \quad (13)$$

Exergy efficiency of the pump;

$$\varepsilon_{pump} = \frac{\dot{E}_{xpump,o} - \dot{E}_{xpump,i}}{\dot{W}_{pump}} \quad (14)$$

Exergy loss of the pump;

$$\dot{I}_{pump} = \dot{W}_{pump} - (\dot{E}_{xpump,o} - \dot{E}_{xpump,i}) \quad (15)$$

Exergy efficiency of air-cooled condenser;

$$\varepsilon_{cond.} = \frac{\Sigma \dot{E}_{xcond,o}}{\Sigma \dot{E}_{xcond,i}} \quad (16)$$

Exergy loss of air-cooled condenser;

$$\dot{I}_{cond.} = \Sigma \dot{E}_{xcond,i} - (\Sigma \dot{E}_{xcond,o} + \dot{W}_{fan}) \quad (17)$$

Exergy efficiency of the fan air-cooled condenser;

$$\varepsilon_{fan} = \frac{\dot{E}_{xfan,o} - \dot{E}_{xfan,i}}{\dot{W}_{fan}} \quad (18)$$

Exergy efficiency of DORA 1 and DORA 2 power plants;

$$\varepsilon_{sys} = 1 - \frac{\sum \dot{E}x_{dest.}}{\sum \dot{E}x_i} = \frac{\dot{W}_{net}}{\sum \dot{E}x_i} \quad (19)$$

Exergy destruction of DORA 1 and DORA 2 plants;

$$\dot{I}_{plant.\ 1,2} = \dot{E}x_{dest.} = \sum \dot{E}x_i - \dot{W}_{net} \quad (20)$$

Thermodynamic parameters given below, are used in evaluating the performance of an existing geothermal system.

Exergetic factor;

$$f_i = \frac{\dot{F}}{\dot{F}_{tot.}} \quad (21)$$

Relative irreversibility;

$$\chi_i = \frac{\dot{I}_i}{\dot{I}_{tot.}} \quad (22)$$

Fuel depletion rate;

$$\delta_i = \frac{\dot{I}_i}{\dot{F}_{tot.}} \quad (23)$$

Productivity lack;

$$\xi_i = \frac{\dot{I}_i}{\dot{P}_{tot.}} \quad (24)$$

4.2. Reference state

Systems dealt with the temperature, pressure, enthalpy, entropy values at that point is the same as the current environmental conditions and the state of the system is a complete state of equilibrium state is called "dead" state. Geothermal fluid production wells at the point where the earth pressure, temperature, enthalpy and entropy value is equal to the values of the current environment of air. In this study the restricted dead state (reference state) is indicated by subscript "0" (P_0, T_0, h_0, s_0, for example.)

4.3. Exergoeconomic analysis

Exergoeconomic is to highlight the total system costs in monetary terms and any thermodynamic analysis of the system, including the initial investment and maintenance costs of the assessment. Researchers such as [e.g., [9–28]] claimed that exergoeconomic analysis can be done basing loss of exergy. In order to do the exergoeconomic analysis, thermodynamic systems should be considered in the initial investment costs and exergy losses.

4.3.1. Determination of key terms

A model developed by Rosen and Dincer, thermo-economic, is used in the thesis study analysis of exergoeconomic [19].

$$\acute{L}_{en} = \text{Output current of waste energy} \quad (25)$$

$$\acute{L}_{ex} = \text{Output current of waste exergy} \quad (26)$$

$$K = \text{Capital cost of the equipment} \quad (27)$$

$$R = \frac{\acute{L}}{K.} \quad (28)$$

4.3.2. Equations of exergoeconomic

Equations used in the exergoeconomic analysis are given below.

$$\acute{L}_{en} = \Sigma_{input}\text{Energy flow} - \Sigma_{output}\text{Energy flow} \quad (29)$$

$$\acute{L}_{ex} = \Sigma_{input}\text{Exergy flow} - \Sigma_{output}\text{Exergy flow} \quad (30)$$

$$R_{en} = \frac{\acute{L}_{en}}{K.} \quad (31)$$

$$R_{ex} = \frac{\acute{L}_{ex}}{K.} \quad (32)$$

5. Results

By using actual field data January 14, 2011 energy and exergy efficiency of DORA 1 and DORA 2 has been defined and exergoeconomic analysis of the plants are calculated. Exergy losses in both the most sections of the system is determined. In this study, reference is taken the last five years, the average ambient temperature of the value of pressure and temperature on the basis of the environmental

Table 3
Results of total uncertainty analysis in the DORA 1 and DORA 2 plants.

Quantities of measured			
Order no	Quantity	Unit	Total uncertainty
1	Pressure	bar	±0.01
2	Temperature	°C	±0.20
3	Volumetric flow rate	m^3/s	±0.15
Quantities of derived			
Order no	Quantity	Unit	Total uncertainty
1	Specific exergy	kJ/kg	±0.32
2	Exergy flow	kW	±0.05
3	Energy flow	kW	±0.06
4	Exergy efficiency	ε	±1.20
5	Energy efficiency	n	±0.50

pressure, environmental temperature of 100.7 kPa; 18.28 °C. I In Table 4 and Table 6 a unit of exergy rates and other features for the facility of DORA 1 and DORA 2 represents the layout of the plant diversity in. Some of the exergy and energy performance information was provided for DORA 1 and DORA 2 plant units. Components belonging to Part I and II are given in Tables 5–7.

5.1. Energy and exergy

The energy flow diagram of DORA 1 and DORA 2 are given in Figs. 5 and 6 44.62% of Total energy generated in Dora 1 is going to the loss Reinjection and in 43.08% of total energy generated in DORA 2 is lost to Reinjection losses. The highest energy loss in both the system partition is in air-cooled condanser and, 49.46% the total energy generated in DORA 1 and DORA 2, the total energy generated in 51.24% of that, is lost to condensation. Total energy efficiency of power stations DORA 1 and DORA 2 temperature change of the reference the connected to the surrounding in Figs. 7 and 8′ is also shown, both in the chart according to the result, if the reference ambient temperature increases, total energy effieciency decreases.

DORA 1 and DORA 2 plants, energy, exergy and exergoeconomic developed to analyze the work of some of the correlations are given below:

- Correlation of the energy efficiency for DORA 1:

$$n_1 = 0.9114e^{-0.0259\ T}{}_a \tag{33}$$

- Correlation of the energy efficiency for DORA 2:

$$n_2 = 0.3063e^{-0.0112\ T}{}_a \tag{34}$$

- Correlation of the total exergy loss for DORA 1:

$$\dot{I}_1 = 29865e^{-0.0053\ T}{}_a \tag{35}$$

Table 4
Thermophysical properties and exergy rates for DORA 1.

No:	Fluid	Fluid phase status	Temperature (°C)	Pressure (kPa)	Enthalpy (kJ/kg)	Entropy (kJ/kgK)	Mass flow rate $\dot{m}$ (kg/s)	Specific exergy e_x (kJ/kg)	Rate of exergy $\dot{E}_x$ (kW)
0	Thermal water	Dead state	18.28	100.71	76.845	0.272	–	0.00	–
0′	*n*-Pentan	Dead state	18.28	100.71	142.500	1.151	–	0.00	–
0″	CO2	Dead state	18.28	100.71	810.070	4.950	–	0.00	–
1	Thermal water	Liquid	165.00	1170.00	697.19	1.991	75.60	119.29	9018.67
2	Thermal water	Liquid	165.00	1170.00	697.19	1.991	75.60	119.29	9018.67
3	Thermal water	Liquid	158.50	670.00	668.685	1.927	72.42	109.63	7939.56
4	Thermal water	Steam	165.00	651.00	2766.153	6.746	3.18	802.56	2552.14
5	Thermal water	Liquid	158.50	670.00	668.685	1.927	72.42	109.63	7939.56
6	Thermal water	Liquid	158.50	908.00	668.826	1.927	72.42	109.77	7949.73
7	Thermal water	Liquid	164.00	692.60	692.571	1.981	72.90	117.56	8570.05
8	Thermal water	Liquid	164.00	692.60	692.571	1.981	72.90	117.56	8570.05
9	Thermal water	Steam	164.00	611.00	2767.021	6.776	3.18	794.75	2527.29
10	Thermal water	Liquid	157.30	580.00	663.436	1.915	69.72	107.88	7521.73
11	Thermal water	Liquid	158.56	600.00	668.904	1.927	69.72	109.68	7646.61
12	Thermal water	Liquid	158.56	817.00	669.032	1.927	69.72	109.80	7655.53
13	Thermal water	Steam	163.00	605.00	2765.103	6.776	6.36	792.85	5042.50
14	Thermal water	Liquid	158.55	700.00	668.919	1.927	142.14	109.72	15,595.69
15	Thermal water	Liquid	130.50	650.00	548.452	1.639	142.14	73.17	10,400.51
16	Thermal water	Liquid	113.90	600.00	477.930	1.461	142.14	54.63	7764.47
17	Thermal water	Liquid	113.90	600.00	477.930	1.461	71.07	54.63	3882.24
18	Thermal water	Liquid	113.90	600.00	477.930	1.461	71.07	54.63	3882.24
19	Thermal water	Liquid	76.40	550.00	319.999	1.031	71.07	21.82	1550.75
20	Thermal water	Liquid	73.00	600.00	305.793	0.990	71.07	19.55	1389.62
21	Thermal water	Liquid	112.90	505.00	473.630	1.450	3.86	53.52	206.61
21a	NCG	Liquid	112.90	505.00	2205.000	6.470	2.03	952.09	1932.73
21b	Thermal water	Liquid	112.90	505.00	473.630	1.450	0.48	53.52	25.69
22	Thermal water	Liquid	113.10	531.00	474.495	1.452	3.86	53.74	207.45
23	Thermal water	Liquid	82.00	531.00	343.472	1.098	146.00	25.86	3775.23
24	Thermal water	Liquid	82.00	1709.00	344.404	1.098	146.00	26.79	3911.20
25	Thermal water	Liquid	81.70	1709.00	343.146	1.095	146.00	26.56	3878.48
26	*n*-Pentan	Steam	137.60	1200.00	706.066	2.654	54.55	125.49	6845.39
27	*n*-Pentan	Steam	75.40	80.00	616.205	2.685	54.55	26.65	1453.83
28	*n*-Pentan	Liquid	30.20	80.00	171.002	1.246	54.55	0.79	42.93
29	*n*-Pentan	Liquid	31.00	1200.00	172.930	1.253	54.55	0.85	46.36
30	*n*-Pentan	Liquid	31.00	1200.00	172.930	1.253	54.55	0.85	46.36
31	*n*-Pentan	Liquid	110.30	1200.00	378.953	1.849	54.55	32.96	1797.92
32	*n*-Pentan	Steam	111.40	750.00	663.333	2.589	63.96	101.63	6500.38
33	*n*-Pentan	Steam	68.00	110.00	600.740	2.600	63.96	35.96	2299.87
34	*n*-Pentan	Liquid	34.90	110.00	182.387	1.283	63.96	1.33	84.93
35	*n*-Pentan	Liquid	35.70	750.00	184.338	1.290	63.96	1.46	93.22
36	*n*-Pentan	Liquid	35.70	750.00	184.338	1.290	63.96	1.46	93.22
37	*n*-Pentan	Liquid	110.30	750.00	378.953	1.849	63.96	32.96	2108.06
38	Air	Ideal gas	15.6	100.71	288.90	1.664	1726.071	0	0
39	Air	Ideal gas	29.6	321.71	302.95	1.711	1726.071	0.198231	342.16078
40	Air	Ideal gas	15.6	100.71	288.90	1.664	1751.627	0	0
41	Air	Ideal gas	30.8	321.71	304.16	1.715	1751.627	0.246211	431.269835

Table 5
Thermophysical properties and exergy rates for DORA 1.

No	Name of equipment	Exergy efficiency ε (%)	Exergy dest $\dot{I}$ (kW)	Heat transfer or power rate Q, $\dot{W}$ (kW)	Rate of energy $\dot{E}$ (kW)	1. law efficiency η (%)
1	Hot water pump 1	27.48	26.83	37.00	10.17	27.48
2	Hot water pump 2	29.72	21.08	30.00	8.92	29.72
3	Evaporator 1	97.16	147.71	17,743.00	17,844.01	–
4	Pre-heater 1	70.27	741.05	10,787.00	12,233.81	–
5	Evaporator 2	79.66	1121.19	18,828.00	21,078.29	–
6	Pre-heater 2	86.42	316.64	12,017.00	12,447.58	–
7	Pre-heater-evaporator 1	88.44	888.76	28,530.00	29,357.07	–
8	Pre-heater-evaporator 2	81.67	1437.83	30,845.00	32,302.43	–
9	Air-cooled condanser 1	24.00	808.74	260.00	24,285.82	–
10	Air-cooled condanser 2	19.00	1523.68	260.00	26,757.86	–
11	Turbine 1	72.00	1509.56	3882.00	4901.92	79.19
12	Turbine 2	83.63	687.51	3513.00	4003.47	87.75
13	Organic pump 1	1.96	171.57	175.00	105.17	60.10
14	Organic pump 2	5.52	141.71	150.00	124.79	83.19
15	Condens pump	11.28	6.65	7.50	3.34	44.52
16	Reinjection pump	36.75	234.03	370.00	135.97	36.75
17	Level 1	45.94	4163.29	3707.00	29,357.07	12.63
18	Level 2	40.86	4631.99	3355.50	32,302.43	10.39
19	Level 1–2	43.40	8795.29	7062.50	61,659.50	11.51
20	Plant	34.71	11,483.22	6105.04	103,196.25	5.92

Table 6
Thermophysical properties and exergy rates for DORA 2.

No:	Fluid	Fluid phase status	Temperature (°C)	Pressure (kPa)	Enthalpy (kJ/kg)	Entropy (kJ/kg K)	Mass flow rate $\dot{m}$ (kg/s)	Specific exergy e_x (kJ/kg)	Rate of exergy $\dot{E}_x$ (kW)
0	Thermal water	Dead state	18.28	100.71	76.845	0.272	–	–	–
0′	*n*-Pentan	Dead dtate	18.28	100.71	142.500	1.151	–	–	–
0″	CO2	Dead state	18.28	100.71	810.070	4.950	–	–	–
1	Thermal water	Liquid	176.00	1591.00	745.496	2.099	112.54	136.15	15,321.92
2	Thermal water	Liquid	176.00	1591.00	745.496	2.099	112.54	136.15	15,321.92
3	Thermal water	Steam	176.00	913.00	2772.760	6.614	2.60	847.65	2,203.90
4	Thermal water	Liquid	176.00	1259.00	745.323	2.099	109.94	135.97	14,948.86
5	Thermal water	Liquid	176.00	1259.00	745.323	2.099	109.94	135.97	14,948.86
6	Thermal water	Liquid	176.00	1259.00	745.323	2.099	109.94	135.97	14,948.86
7	Thermal water	Liquid	174.00	1618.00	736.738	2.080	117.96	133.09	15,699.33
8	Thermal water	Liquid	174.00	1618.00	736.738	2.080	117.96	133.09	15,699.33
9	Thermal water	Steam	174.00	871.00	2770.914	6.630	2.45	841.08	2,060.64
10	Thermal water	Liquid	174.00	1254.00	736.544	2.080	115.51	132.90	15,350.91
11	Thermal water	Liquid	174.00	1254.00	736.544	2.080	115.51	132.90	15,350.91
12	Thermal water	Liquid	174.00	1254.00	736.544	2.080	115.51	132.90	15,350.91
13	Thermal water	Steam	170.00	792.00	2767.037	6.663	5.05	827.75	4,180.13
14	Thermal water	Liquid	169.00	1180.00	714.632	2.031	225.45	125.24	28,234.24
15	Thermal water	Liquid	124.40	1180.00	522.861	1.574	225.45	66.56	15,006.09
16	Thermal water	Liquid	100.00	1130.00	419.621	1.306	225.45	41.37	9,326.48
17	Thermal water	Liquid	100.00	1130.00	419.621	1.306	112.72	41.37	4,663.03
18	Thermal water	Liquid	100.00	1130.00	419.621	1.306	112.72	41.37	4,663.03
19	Thermal water	Liquid	71.20	1130.00	298.687	0.969	112.72	18.81	2,120.41
20	Thermal water	Liquid	71.20	1130.00	298.687	0.969	112.72	18.81	2,120.41
21	Thermal water	Liquid	96.90	1140.00	406.570	1.271	2.25	38.57	86.79
21a	NCG	Liquid	91.20	940.00	3055.330	7.910	2.69	1382.76	3,719.62
21b	Thermal water	Liquid	91.20	940.00	382.437	1.206	0.10	33.50	3.25
22	Thermal water	Liquid	97.30	1170.00	408.270	1.276	2.25	38.96	87.66
23	Thermal water	Liquid	69.21	976.00	290.232	0.944	227.71	17.44	3,972.29
24	Thermal water	Liquid	69.16	1300.00	290.288	0.944	113.85	17.68	2,012.41
25	Thermal water	Liquid	69.10	1300.00	290.037	0.943	113.85	17.63	2,007.06
26	Thermal water	Liquid	69.16	1319.00	290.304	0.944	113.85	17.68	2,012.86
27	Thermal water	Liquid	68.20	1319.00	286.280	0.932	113.85	17.11	1,947.59
28	*n*-Pentan	Steam	136.00	1149.00	704.000	2.640	116.61	127.56	14,874.86
29	*n*-Pentan	Steam	81.30	177.00	624.074	2.637	116.61	48.57	5,663.43
30	*n*-Pentan	Liquid	40.40	177.00	195.830	1.326	116.61	2.21	258.08
31	*n*-Pentan	Liquid	41.50	1070.00	198.540	1.335	116.61	2.42	281.83
32	*n*-Pentan	Liquid	41.50	1070.00	198.540	1.335	116.61	2.42	281.83
33	*n*-Pentan	Liquid	89.20	1070.00	321.038	1.695	116.61	19.91	2,322.01
34	*n*-Pentan	Steam	95.30	440.00	641.476	2.5838	92.24	81.42	7,509.73
35	*n*-Pentan	Steam	67.70	125.00	599.507	2.600	92.24	34.70	3,200.34
36	*n*-Pentan	Liquid	38.80	125.00	191.910	1.314	92.24	1.93	178.04
37	*n*-Pentan	Liquid	39.50	440.00	193.625	1.319	92.24	2.05	188.92
38	*n*-Pentan	Liquid	39.50	440.00	193.625	1.319	92.24	2.05	188.92
39	*n*-Pentan	Liquid	92.30	440.00	328.580	1.700	92.24	26.08	2,406.07
40	Air	Ideal gas	16.3	100.71	289.60	1.666	3029.822	0	0
41	Air	Ideal gas	32.7	445.00	306.07	1.721	3029.822	0.349045	1,057.5442
42	Air	Ideal gas	16.3	100.71	289.60	1.666	3197.41	0	0
43	Air	Ideal gas	28.0	445.00	301.35	1.706	3197.41	0.13971	446.71015

Table 7
Thermophysical properties and exergy rates for DORA 2.

No	Name of equipment	Exergy efficiency ε (%)	Exergy dest $\dot{I}$ (kW)	Heat Transfer or Power Rate $\dot{Q}$, $\dot{W}$ (kW)	Rate of Energy $\dot{E}$ (kW)	1. law efficiency η (%)
1	Evaporator 1	94.89	675.31	44,330.00	43,234.66	–
2	Pre-heater 1	80.24	502.44	14,070.00	13,631.69	–
3	Evaporator 2	84.36	946.44	29,910.00	18,472.75	–
4	Pre-heater 2	87.20	325.47	13,930.00	13,631.69	–
5	Pre-heater-evaporator 1	92.53	1,177.74	58,400.00	56,866.35	–
6	Pre-heater-evaporator 2	85.20	1,271.91	43,840.00	41,710.08	–
7	Air-cooled condanser 1	25.00	3,942.81	405.00	49,937.53	–
8	Air-cooled condanser 2	15.00	2,170.59	405.00	37,596.75	–
9	Turbine 1	95.49	415.42	8,796	9,320.17	94.38
10	Turbine 2	55.77	1,905.91	2,403.48	3,871.22	62.09
11	Organic pump 1	6.99	316.25	340.00	316.01	92.95
12	Organic pump 2	5.73	179.12	190.00	158.19	83.26
13	Condens pump	17.49	4.13	5	3.82	76.50
14	Reinjection pump	29.43	127.02	180.00	11.76	6.53
15	Level 1	51.46	7,659.77	8,456.00	150,676.97	5.61
16	Level 2	25.70	6,574.23	2,208.48	41,710.08	5.29
17	Level 1–2	38.58	14,234.00	10,664.48	192,387.05	5.54
18	Plant	31.19	17,392.12	9,675.52	170,803.77	5.66

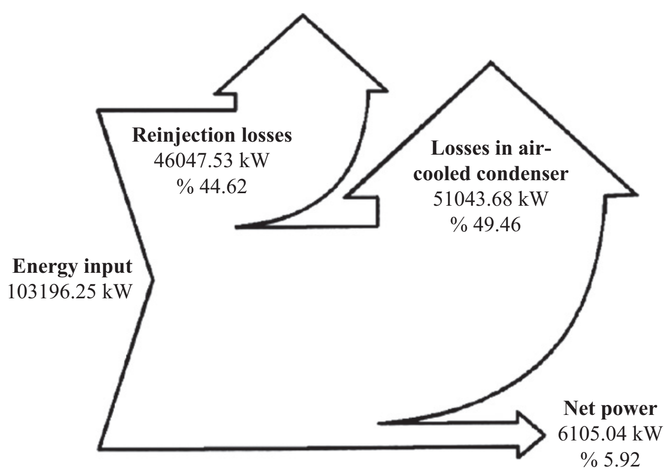

Fig. 5. Energy flow diagram of DORA 1.

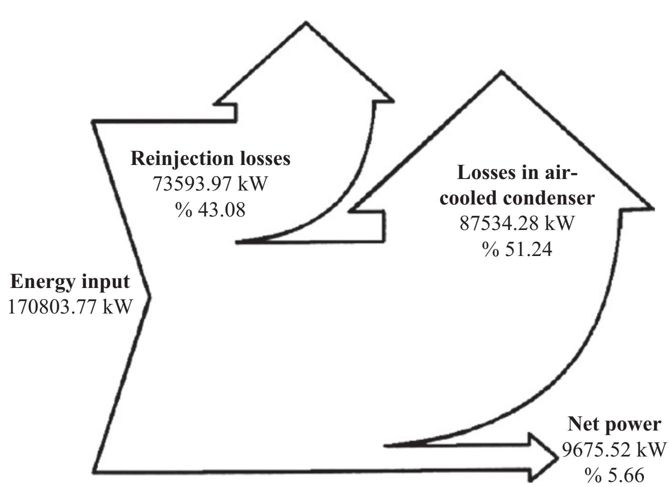

Fig. 6. Energy flow diagram of DORA 2.

- Correlation of the total exergy loss for DORA 2:

$$\dot{I}_2 = 28230e^{-0.019\,T_a} \tag{36}$$

- Correlation of the total exergy efficiency for DORA 1:

$$\varepsilon_1 = 31.449e^{0.0041\,T_b} \tag{37}$$

- Correlation of the total exergy efficiency for DORA 2:

$$\varepsilon_2 = 24.229e^{0.0135\,T_b} \tag{38}$$

- Correlation of the ORC output temperature for DORA 1:

$$T_1 = 75.289e^{0.0111\,\varepsilon_a} \tag{39}$$

- Correlation of the ORC output temperature for DORA 2:

$$T_2 = 81.157e^{0.0104\,\varepsilon_a} \tag{40}$$

- Correlation of the inefficiency ratio for DORA 1:

$$\xi_1 = 44.496e^{0.0299\,T_a} \tag{41}$$

- Correlation of the inefficiency ratio for DORA 2:

$$\xi_2 = 42.839e^{0.0062\,T_a} \tag{42}$$

- Correlation of the the rate of fuel consumption for DORA 1:

$$\delta_1 = 95.545e^{-0.0099\,T_a} \tag{43}$$

- Correlation of the the rate of fuel consumption for DORA 1:

$$\delta_2 = 69.796e^{-0.0059\,T_a} \tag{44}$$

- Correlation of the value of R_{en} for DORA 1:

$$R_{en1} = 0.0059e^{-0.0066\,T_a} \tag{45}$$

- Correlation of the value of R_{en} for DORA 2:

$$R_{en2} = 0.095e^{-0.0018\,T_a} \tag{46}$$

- Correlation of depending on the temperature of the reference the value of R_{ex} for DORA 1:

$$R_{ex1} = 0.0013e^{-0.0053\,T_a} \tag{47}$$

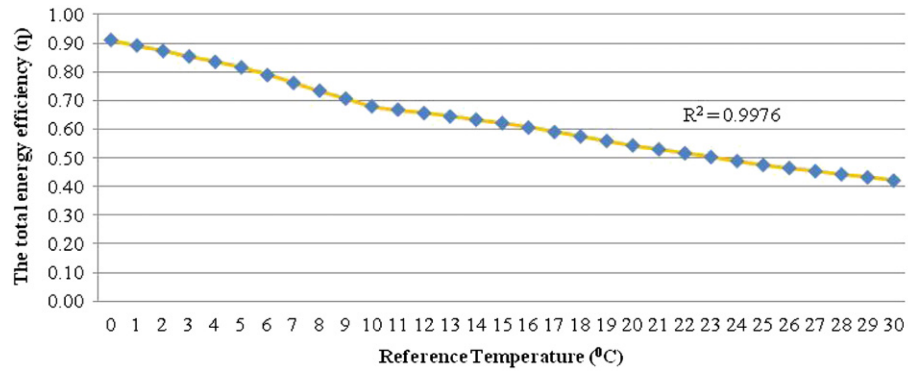

Fig. 7. Change of depending on the reference surrounding temperature of the energy efficiency of DORA 1 power plant.

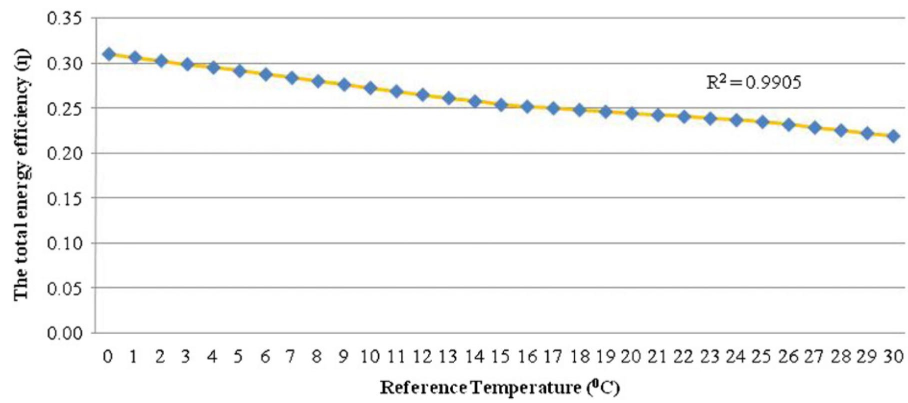

Fig. 8. Change of depending on the reference surrounding temperature of the energy efficiency of DORA 2 power plant.

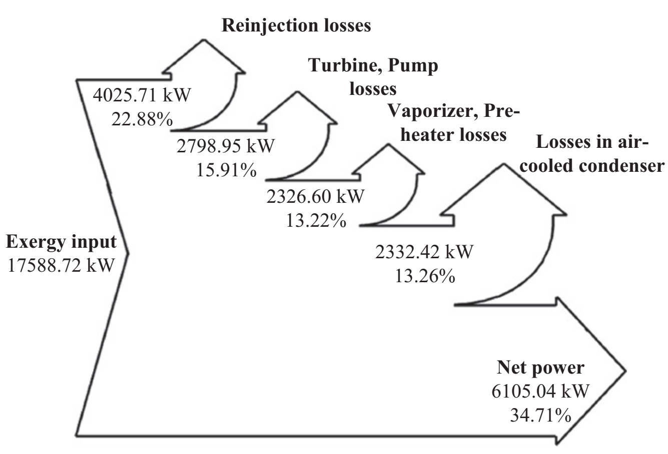

Fig. 9. Exergy flow diagram of DORA 1.

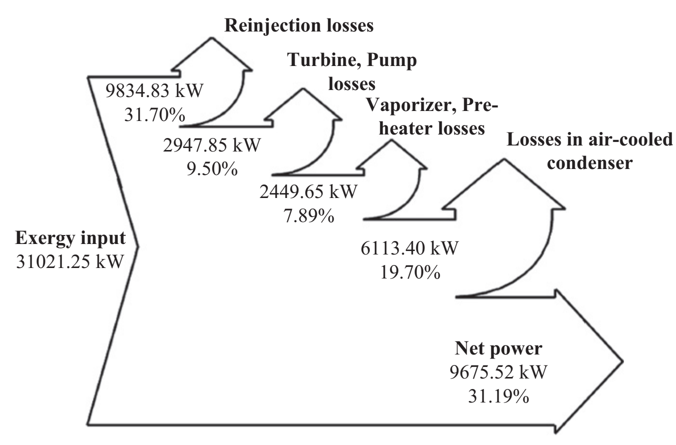

Fig. 10. Exergy flow diagram of DORA 2.

- Correlation of depending on the temperature of the reference the value of R_{ex} for DORA 2:

$$R_{ex2} = 0.0008e^{-0.018\ T_a} \tag{48}$$

- Correlation of depending on the exergy efficiency of the reference the value of R_{ex} for DORA 1:

$$R_{ex3} = 0.0078e^{-0.0622\ \varepsilon_a} \tag{49}$$

- Correlation of depending on the exergy efficiency of the reference the value of R_{ex} for DORA 2:

$$R_{ex4} = 0.0209e^{-0.0814\ \varepsilon_a} \tag{50}$$

In these correlations, Ta (°C) shows the reference ambient temperature, T_b (°C) shows brine (thermal water) temperature, T_c (°C) shows outlet temperature of the ORC, ε_a plant's shows exergy efficiency. Change of the reference to energy efficiency of DORA 1 and DORA 2, depending on the surrounding temperature is given in Figs. 7 and 8.

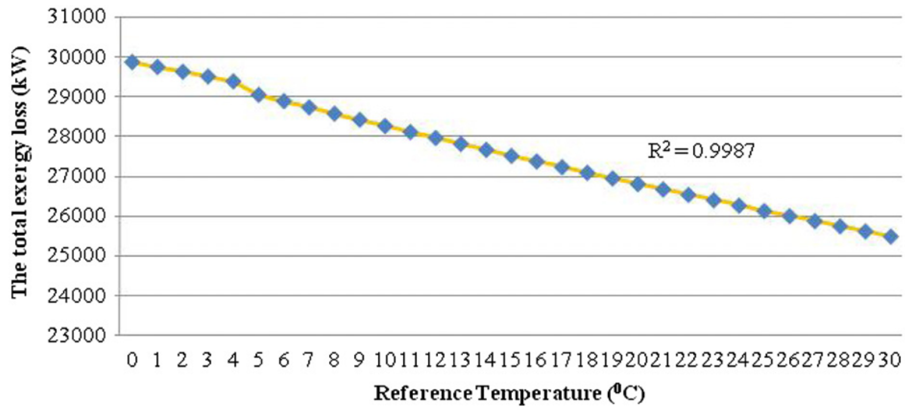

Fig. 11. Change of depending on the reference surrounding temperature of the total exergy loss of DORA 1 power plant.

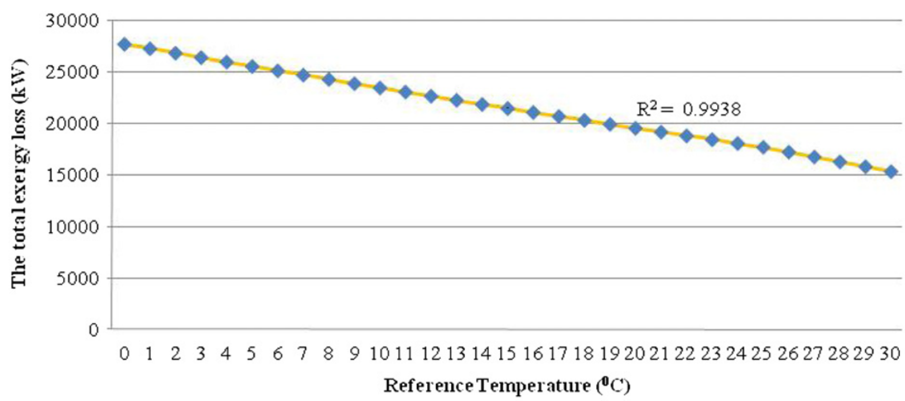

Fig. 12. Change of depending on the reference surrounding temperature of the total exergy loss of DORA 2 power plant.

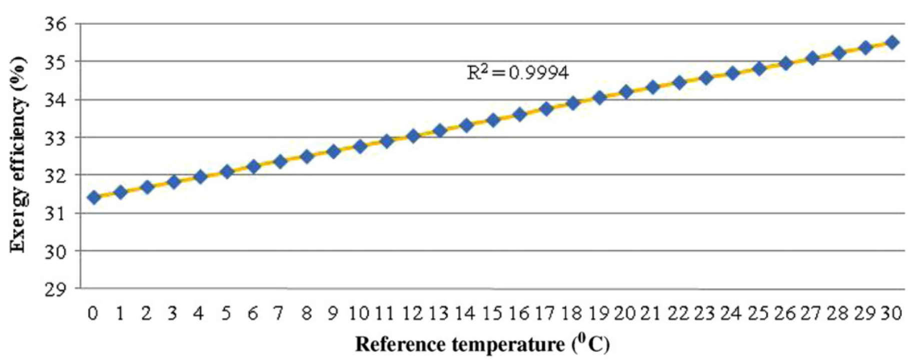

Fig. 13. Change of depending reference surrounding temperature of the total exergy efficiency of DORA 1 power plant.

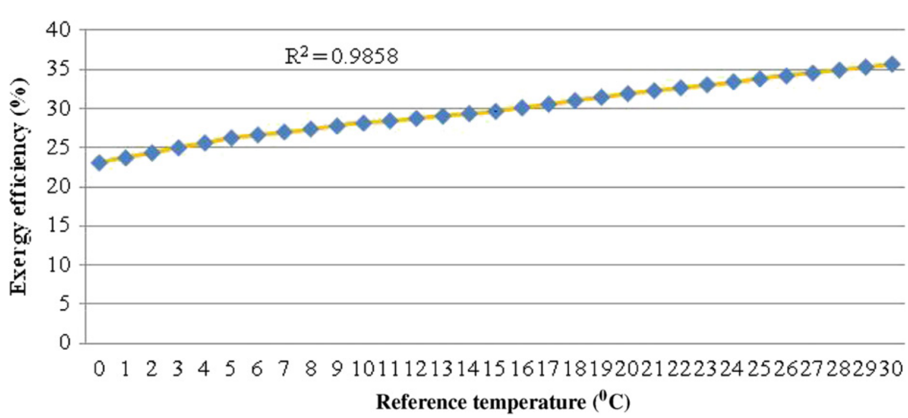

Fig. 14. Change of depending reference surrounding temperature of the total exergy efficiency of DORA 2 power plant.

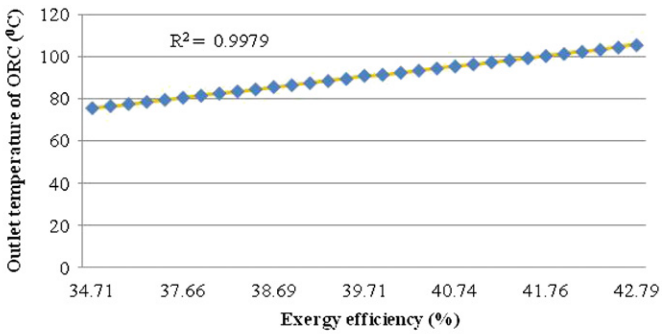

Fig. 15. Change of depending on the exergy efficiency of the ORC exit temperature of DORA 1 power plant.

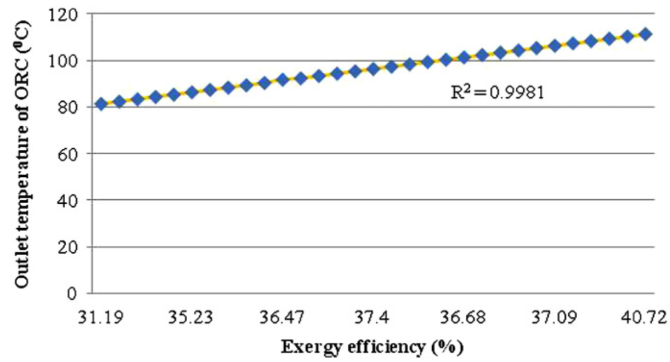

Fig. 16. Change of depending on the exergy efficiency of the ORC exit temperature of DORA 2 power plant.

Table 8
Energy, exergy and values of thermodynamic parameter in the DORA 1 plant.

No	Name of equipment	Exergy efficiency ε(%)	Exergy dest $\dot{I}$ (kW)	Produced and consumed work (kW)	Energy (kW)	$\dot{P}$ (kW)	$\dot{F}$ (kW)	1. law efficiency η (%)
1	Hot water pump 1	27.48	26.83	37.00	10.17	10.17	37.00	27.48
2	Hot water pump 2	29.72	21.08	30.00	8.92	8.92	30.00	29.72
3	Evaporator 1	97.16	147.71	17,743.00	17,844.01	5,047.48	5,195.18	–
4	Pre-heater 1	70.27	741.05	10,787.00	12,233.81	1,751.56	2,492.61	–
5	Evaporator 2	79.66	1,121.19	18,828.00	21,078.29	4,392.32	5,513.51	–
6	Pre-heater 2	86.42	316.64	12,017.00	12,447.58	2,014.84	2,331.49	–
7	Pre-heater-evaporator 1	88.44	888.76	28,530.00	29,357.07	6,799.03	7,687.79	–
8	Pre-heater-evaporator 2	81.67	1,437.83	30,845.00	32,302.00	6,407.16	7,844.99	–
9	Air-cooled condanser 1	24.00	808.74	260.00	24,285.82	42.93	1,453.83	–
10	Air-cooled condanser 2	19.00	1,523.68	260.00	26,757.86	84.93	2,299.87	–
11	Turbine 1	72.00	1,509.56	3,882.00	4901.92	3,882.00	5,391.56	79.19
12	Turbine 2	83.63	687.51	3,513.00	4003.47	3,513.00	4,200.51	87.75
13	Organic pump 1	1.96	171.57	175.00	105.17	3.43	175.00	60.10
14	Organic pump 2	5.52	141.71	150.00	124.79	8.29	150.00	83.19
15	Condens pump	11.28	6.65	7.50	3.34	0.85	7.50	44.52
16	Reinjection pump	36.75	234.03	370.00	135.97	135.97	370.00	36.75
17	Level 1	45.94	4,163.29	3,707.00	29,357.07	3,878.57	7,687.79	12.63
18	Level 2	40.86	4,631.99	3,355.50	32,302.43	3,504.71	7,844.99	10.39
19	Level 1–2	43.40	8,795.29	7,062.50	61,659.50	6,626.00	15,532.79	11.51
20	Plant	34.71	11,483.2	6,105.04	10,3196.2	6,626.00	17,588.72	5.92

Table 9
Energy, exergy and values of thermodynamic parameter in the DORA 2 plant.

No	Name of equipment	Exergy efficiency ε (%)	Exergy dest $\dot{I}$ (kW)	Produced and consumed work (kW)	Energy (kW)	$\dot{P}$ (kW)	$\dot{F}$ (kW)	Law efficiency η (%)
1	Evaporator 1	94.89	675.31	44,330.00	43,234.66	12,552.84	13,228.15	–
2	Pre-heater 1	80.24	502.44	14,070.00	13,631.69	2,040.18	2,542.62	–
3	Evaporator 2	84.36	946.44	29,910.00	18,472.75	5,103.65	6,050.09	–
4	Pre-heater 2	87.20	325.47	13,930.00	13,631.69	2,217.15	2,542.62	–
5	Pre-heater-evaporator 1	92.53	1,177.74	58,400.00	56,866.35	14,593.02	15,770.77	–
6	Pre-heater-evaporator 2	85.20	1,271.91	43,840.00	41,710.08	7,320.80	8,592.71	–
7	Air-cooled condanser 1	25.00	3,942.81	405.00	49,937.53	258.08	5,663.43	–
8	Air-cooled condanser 2	15.00	2,170.59	405.00	37,596.75	178.04	3,200.34	–
9	Turbine 1	95.49	415.42	8,796.00	9,320.17	10,664.48	9,211.42	–
10	Turbine 2	55.77	1,905.91	2,403.48	3,871.22	9,675.52	4,309.39	–
11	Organic pump 1	6.99	316.25	340.00	316.01	23.75	340.00	-
12	Organic pump 2	5.73	179.12	190.00	158.19	10.88	190.00	83.26
13	Condens pump	17.49	4.13	5	3.82	0.87	5.00	76.50
14	Reinjection pump	29.43	127.02	180.00	11.76	52.98	180.00	6.53
15	Level 1	51.43	7,659.77	8,456.00	150,676.97	8,456.00	15,770.77	5.61
16	Level 2	25.70	6,574.23	2,208.48	41,710.08	2,208.48	13,370.89	5.29
17	Level 1–2	38.58	14,234.00	10,664.48	192,387.05	10,664.48	29,141.66	5.54
18	Plant	31.19	17,392.12	9,675.52	170,803.77	10,484.48	31,021.25	5.66

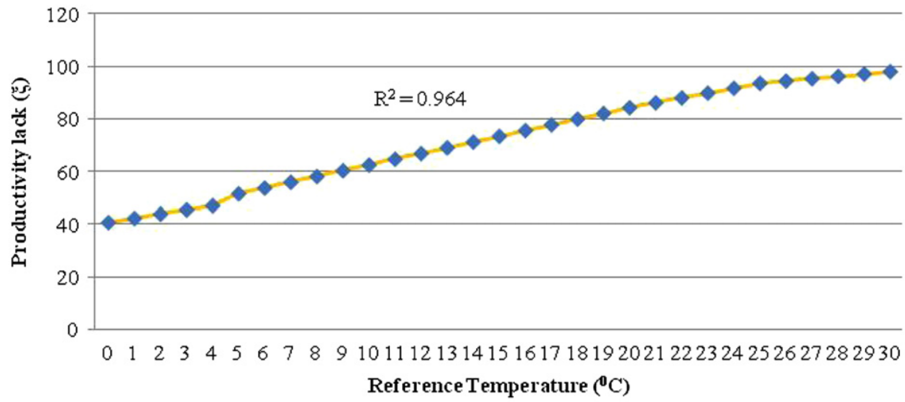

Fig. 17. Change of depending on the reference surrounding temperature of the productivity lack of DORA 1 power plant.

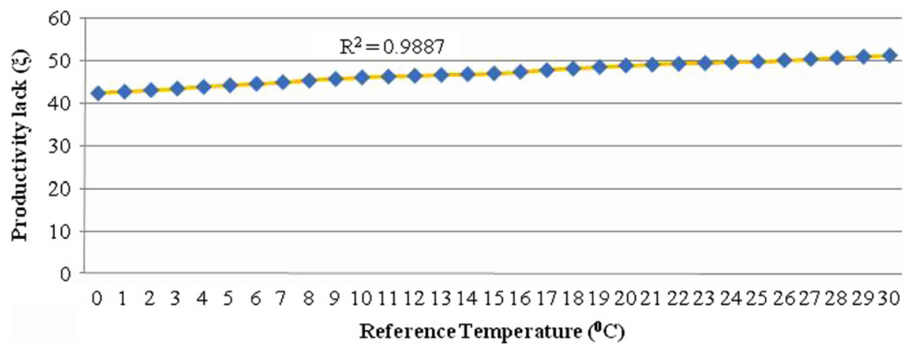

Fig. 18. Change of depending on the reference surrounding temperature of the productivity lack of DORA 2 power plant.

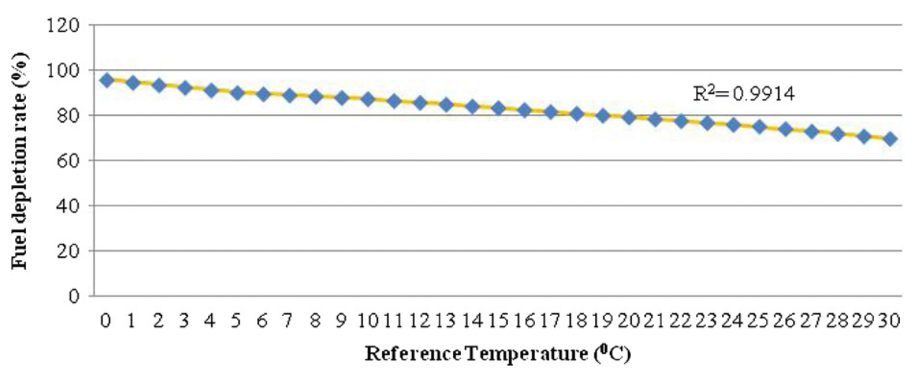

Fig. 19. Change of depending on the reference surrounding temperature of the fuel depletion rate of DORA 1 power plant.

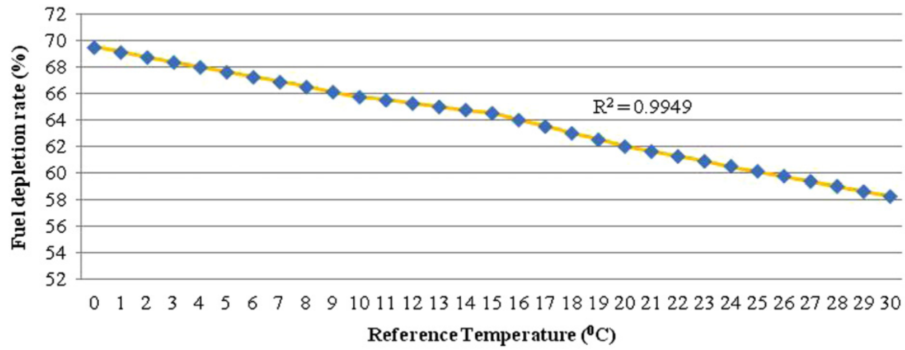

Fig. 20. Change of depending on the reference surrounding temperature of the fuel depletion rate of DORA 2 power plant.

Table 10
DORA 1 and DORA 2 plant's exergoeconomic parameter values (U.S. dollars are used in 2011).

No	Name of power plants	Exergy destruction $\acute{L}_{ex}$ (W)	Energy loss $\acute{L}_{en}$ (W)	R_{ex} W/TL	R_{en} W/TL	$\acute{L}_{ex}$ (W)	$\acute{L}_{en}$ (W)	R_{ex} W/TL	R_{en} W/TL
1	DORA 1	$\dot{I}_{plant\ \ 1,2} = \dot{E}x_{destruction} = \sum \dot{E}x_i - \dot{W}_{net}$	$\eta = \frac{\sum \dot{E}_o}{\sum \dot{E}_i} = \frac{\dot{W}_{net}}{\sum \dot{E}_i}$	$\acute{L}_{ex1}/K_1$	$\acute{L}_{en1}/K_1$	11,483220	53,097,000.0	0.506315	2.3411
2	DORA 2	$\dot{I}_{plant\ \ 1,2} = \dot{E}x_{destruction} = \sum \dot{E}x_i - \dot{W}_{net}$	$\eta = \frac{\sum \dot{E}_o}{\sum \dot{E}_i} = \frac{\dot{W}_{net}}{\sum \dot{E}_i}$	$\acute{L}_{ex2}/K_2$	$\acute{L}_{en2}/K_2$	17,392,120	105,190,050.0	0.511232	3.092

Explanation: K_1=The cost of power plant investment in DORA 1=18,000,000 dollar (x1.26TL): K_2=The cost of power plant investment in DORA 2=27,000,000 dollar (x1.26TL).

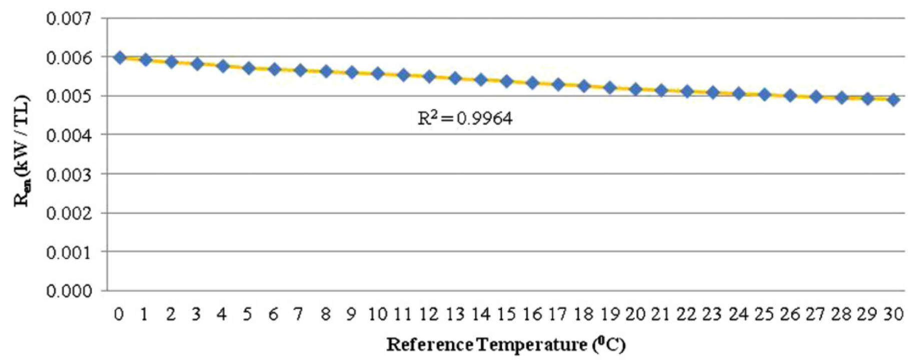

Fig. 21. Change of depending on the reference surrounding temperature of the value of R_{en} of DORA 1 power plant.

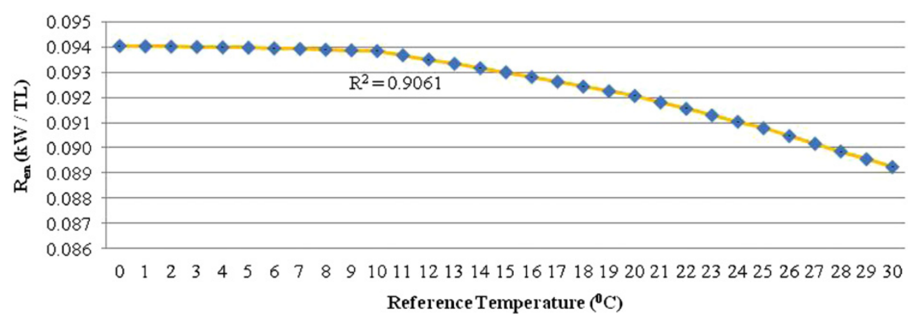

Fig. 22. Change of depending on the reference surrounding temperature of the value of R_{en} of DORA 2 power plant.

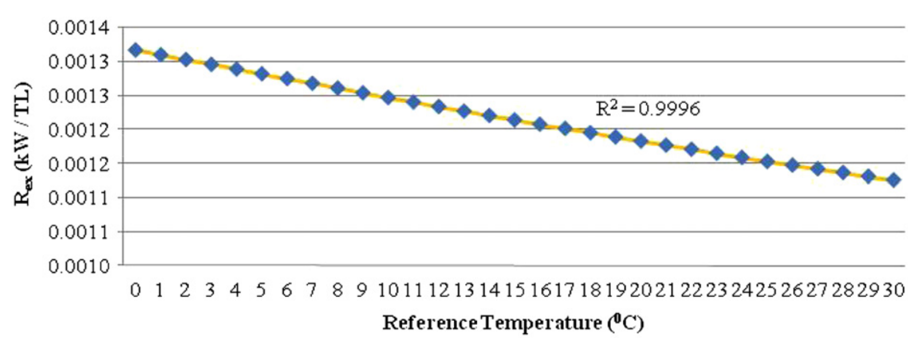

Fig. 23. Change of depending on the reference surrounding temperature of the value of R_{ex} of DORA 1 power plant.

The exergy flow diagram of DORA 1 and DORA 2, is given in Figs. 9 and 10 22.88% of total produced in exergy DORA 1 percent is going to loss of Drainage, Drainage DORA 2 in 31.7% of total manufactured exergy is lost. Both air-cooled condenser system exergy losses DORA 1′ in 13.26% of total manufactured exergy percent of that, DORA 2′ in 19.70% of total manufactured exergy ′representative. Figs. 11 and 12′, respectively; DORA 1 and DORA 2 power stations connected to the surrounding temperature change of the total exergy loss of the reference, Figs. 13 and 14 in DORA 1 and DORA 2 plants depend on the temperature change of exergy efficiency, Figs. 15 and 16′ DORA 1 and DORA 2 plants in the ORC output shows the variation due to temperature exergy efficiency.

DORA 1 and DORA 2 plants, energy, exergy and thermodynamic parameter values in Tables 8 and 9 are also given. Figs. 17 and 18 in DORA 1 and DORA 2 plants of inefficiency due to an ambient

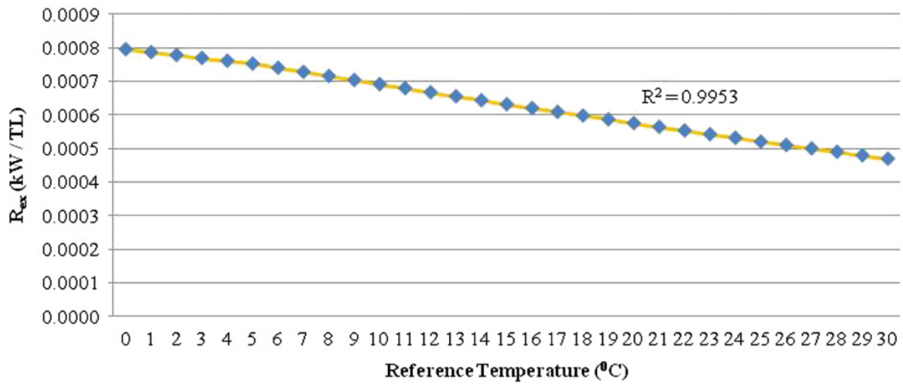

Fig. 24. Change of depending on the reference surrounding temperature of the value of R_{ex} of DORA 2 power plant.

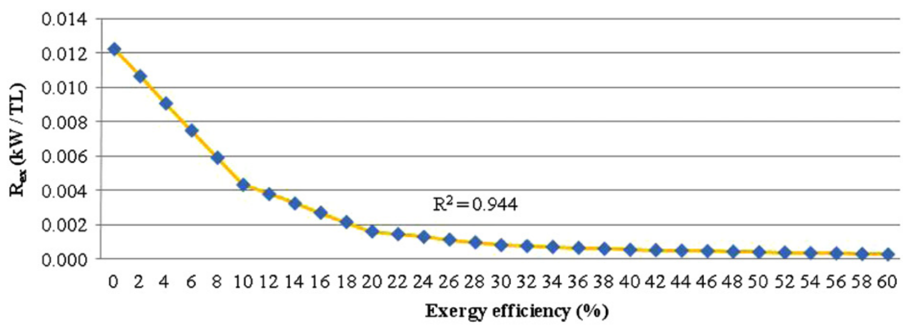

Fig. 25. Change of depending on the exergy efficiency of the value of R_{ex} of DORA 1 power plant.

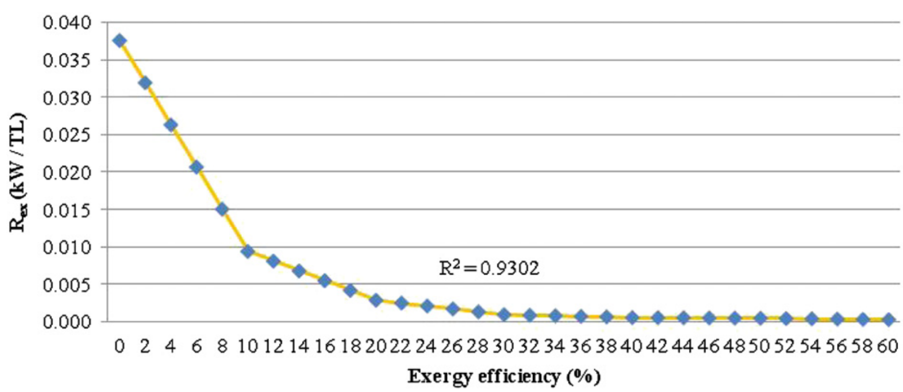

Fig. 26. Change of depending on the exergy efficiency of the value of R_{ex} of DORA 2 power plant.

temperature of the reference exchange rate, were drawn in Figs. 19 and 20 DORA 1 and DORA 2 plants due to environmental temperature of the fuel consumption rate of change of reference.

5.2. Exergoeconomic results

In Table 10 Exergoeconomic parameter values of DORA 1 and DORA 2 are given. Accordingly, the value of DORA 1 0.506315 R_{ex}, R_{ex} DORA 2 value was found to be 0.511232.

In Figs. 21 and 22 the reference value of DORA 1 plants R_{en} change depending on environmental temperature is given, in Figs. 23 and 24 in DORA 1 and DORA 2 power stations connected to the surrounding temperature change of the reference value of R_{ex} is given and in Figs. 25 and 26 the change due to exergy efficiency in DORA 1 and DORA 2 is given in value of R_{ex}.

6. Conclusions

The net power generated from plants varies of depending on the air temperature for air cooling was carried out the both in DORA 1 and DORA 2 plants. So that the cooling process which will take place with the increase in air temperature during the summer months, is very small compared to winter months. This also results in decreased productivity of the plants.

Air-cooled condenser loss in DORA 2 is high as per cent level in the DORA 1. Losses of percent of the turbine and pump also differ in the DORA 1 and DORA 2. In this differences are indicators vary depending on daily operating conditions of the plant concerned. Therefore specific to commissioned energy–exergy efficiency studies should be monitored closely. Overall energy management studies in the plant should be regularly conducted.

Daily exergetic and energetic performances of the basic equipment as a turbine, pump, condenser, evaporator in the plant should be monitored.

In this way, will be executed a more healthy possible improvement works in the plant.

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